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Planning for rural energy system: part II

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Abstract

This paper discusses the central importance of energy inputs in development, and presents the complex interactions within subsystems that contribute a Rural Energy System. This paper also brings about the importance of the primary data for realistic renewable energy planning at the micro level in a given rural system. Factors that render secondary data somewhat inadequate for such applications are discussed. The differences between energy related data from secondary and primary sources in respect of representative villages in Kanyakumari District of Tamil Nadu, India, are detailed. A rural system model for computing the output from various components of a rural system is also presented. This projection is made by making use of a set of technical coefficients, which relate the inputs to the outputs from individual segments of the rural production system. While some of the technical coefficients are developed based on previously published data, a large number have been quantified on the basis of careful survey. The usefulness of the model is discussed. The paper also presents a Linear Programming Model for optimum resource allocation in a rural system. The objective function of the Linear Programming Model is maximizing the revenue of the rural system where in optimum resource allocation is made subject to a number of energy and non-energy related relevant constraints. The model also quantifies the major yields as well as the byproducts of different sectors of the rural economic system. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Rural energy planning; Primary data; Secondary data; Cropping and irrigation intensity; Operational holdings; Occupation; Energy intensity; Rural system model; Rural subsystem; Energy interaction; Technical coefficients; Micro level development

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1. Introduction

Energy is a key factor affecting economic development at the micro level. Since India's economic prosperity depends on the rural economy, it is imperative to take a close look at the energy scene of the rural system. A rural system functions as an integral whole with several interacting subsystems, such as, households, agriculture, livestock, rural industries, and rural transportation. All the subsystems of the rural system are interlinked, and interdependant in several ways. In a given rural system, a subsystem's output, in general, have multiple of usages, and may form the input to one or more subsystems.

Quantifying the available energy resources and the present energy consumption pattern in the rural system is an important step in the planning process, since these determine the dynamics of the changes in the energy demand and supply patterns. A rural system consumes energy in several forms like manual labour, animal power, crop residues, biomass, fuelwood, kerosene, diesel, electricity, chemical fertilizers, farm yard manure, feeds, etc., and also produces energy in several forms—manual labour, drought animal power, crop residues, and other biomass, along with nutritional energy in the form of several farm products, fat, protein, etc. Appropriate policies for micro level planning of a rural system must also take into account the complex energy related interactions within the system. This complexity in the Indian rural scene arises from multiple or alternative uses for products like crop residues, which find application as fuel, feed, and even fertilizer.

The immediate major concern in any developing country is raising the standard of the living of the people. Keeping this point in view, the author tries to maximize the total revenue in the rural system. A linear programming model for the Rural Energy Systems (RES) developed by Parikh [2] was employed in this present investigation with some modifications. A number of technical coefficients for the model have been computed on the basis of standard data available in literature, while many are data obtained from the survey. The model quantifies the micro level energy related interactions within the rural system and also allocates optimum resources to different subsystems of the system. Since the results obtained for any model are as good or as bad as the data input, are authentic database is an important requirement for realistic planning. Therefore, a micro level plan must be based on micro level

data, which can be obtained through primary and or secondary sources. However, data from the secondary sources invariably suffer from several lacunae. Some of these are non-uniform quality and training of the personal compiling data inherent delay resulting in data skew due to time lag between the data collection and publication, and inadequate information or lack of information about local influence factors in secondary data.

This paper examines the issue in detail and presents a study comparing and contrasting data from secondary sources and a primary survey for Kanyakumari District of Tamil Nadu, India. The impact of some of the local influence factors on energy consumption in the area, clearly brought out by primary data, is also discussed. Though the objectives of the allocation model is maximization of the revenue in the rural system, energy related constraints were developed, and incorporated in the model for ensuring compatibility of energy related interactions. The model computes the total revenue obtained from the rural system. It also quantifies the yield of the major crops and their byproducts, dung, fuelwood produced in the system and energy consumption by different subsystem. This model allocates the energy resources to different subsystem of the system. For model validation, the outputs for the sample farms were calculated from the knowledge of the inputs and technical coefficients for the base year 1989, and the results were compared with the actual data. The model was also used for projecting the output for the District as a whole.

2. Lacunae in secondary data

In many countries Governments usually award projects to various non-government organizations which collect, compile, and analyze the data, and finally prepare reports on various themes. Many of these organizations normally employ project personnel after getting specific projects. Thus, in a number of cases relatively untrained personnel, having little experience of survey work or any other form of data collection, are engaged for such work. Consequently, erroneous data entry, bias in data collection, etc. are very common. Also the secondary level data available in even the most recent literature or document form are more often nearly a decade old on account of the long process of schedule preparation, collection, processing and compilation of data, and report writing and publication. For compiling authentic survey data, it is essential to cross check the data at various stages, which is highly improbable in a situation when diverse organizations employing personnel with inadequate training and experience are involved in most stages from data collection to report writing.

3. Importance of primary data

Improper scheduling is another problem in data collection. For a vast country like India, administering the survey also creates problems. Thus, the same survey is conducted in different locations with different time lags. In such circumstances, the

information collected from different locations at different times is likely to have an inherent skew.

These factors would have an adverse bearing on database required for a micro level plan, rendering data from secondary sources somewhat inadequate. Therefore, an appropriate micro level plan must place greater emphasis on current primary level data. Some of the factors which make recourse to primary sources of data very important are enumerated below.

3.1. Focus on specific objectives

A micro level plan is normally prepared for fulfilling some specific objectives, and thus requires data specifically pertaining to these objectives. In most cases the data available from secondary sources do not satisfy such requirements and specific data may have to be collected.

3.2. Need for current data for short term planning

Micro level plans often aim to fulfill short-term needs, for which current data would be essential. Secondary data would normally not serve the purpose because of considerable and often indeterminate period over which such data is collected, compiled and published.

3.3. Consideration of local influence parameters

Micro level planning must also focus attention on local influence parameters which may change in accordance with specific local needs, conditions, and aspirations. Hence, collection of current data in respect of the local influence factors is very essential. Collection of statistical data in respect of several locally important aspects, like food preference, alternative uses of single resources, etc., is also important for many studies.

For the present investigation, the pattern of energy consumption, and the demand and the supply of energy were carefully examined. At the outset, the author had detailed discussion with administrative officials at various levels, with village heads, and a cross section of the villagers for identifying the various influence factors responsible for changes in energy consumption, demand and supply in the locality. The development of the schedules and the method of administration of the survey have been presented in a recent paper [1].

Energy consumption in different types of activities like households, agriculture, commerce, etc. is influenced by several significant parameters. The dependence of energy consumption on several significant attributes like farm sizes, cropping pattern, cropping and irrigation intensity, etc. can only clearly brought out, with the help of the primary data.

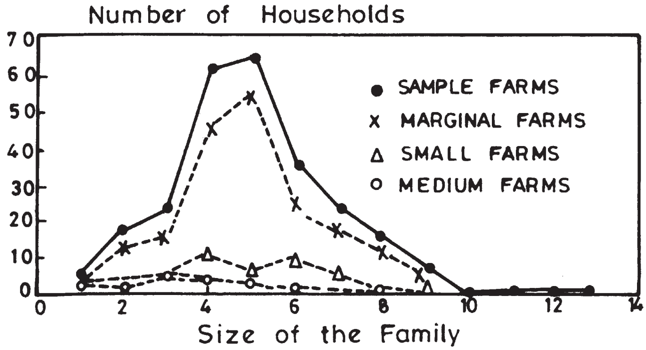

Fig. 1. Household distribution by family size.

4. Major local influence parameters

4.1. Distribution of households

Fig. 1 shows the distribution of number of households vs the size of the family and reveals the average size of the family is about five in all sample farms. The relatively flat family size distribution for small and medium farms is possibly due to the small sample size. Fig. 2 shows the number of households against their operational holdings and reveals that about seventy five per cent of the households belong to the marginal farm category (below 1.00 ha of land). This also clear from Fig. 3, depicting the percentage distribution of population against farm size.

4.2. Population distribution

Population is an important parameter having a direct bearing on consumption, demand and supply of energy in a rural system. Since the study area has a high population density, the size of most of the holdings, and the per capita availability

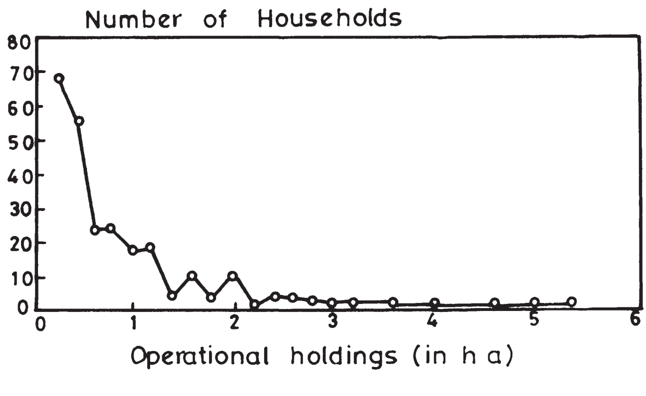

Fig. 2. Distribution of households by operational holdings.

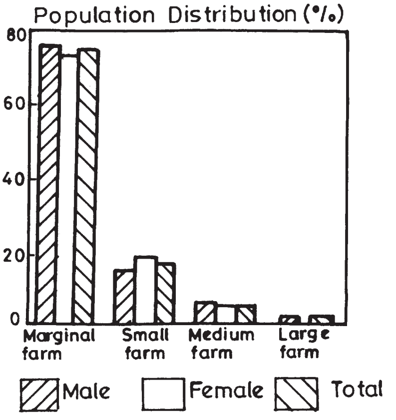

Fig. 3. Holding sizewise population distribution.

of land are very small. As a consequence, while there is an increased demand for energy to meet the basic requirements, the increased pressure on land leads to a decrease in the energy supply potential. In this situation, the rural population has to either opt for purchased energy, or perforce has to search alternative sources to meet its basic requirements. The size of operational holding has very significant influence on consumption, demand and supply of energy in the rural system. Hence, it is essential to take a close look at the population distribution in the rural system in terms of the size of farms. For the present study, the sample households were divided into four categories, namely marginal farm, small farm, medium farm and large farm according to their size.[1] Fig. 3 also shows the relative percentage of male and female population in the area.

4.3. Occupation

Occupation is another factor which affects energy consumption in rural areas. Households having service and business as their primary and secondary occupation tend to consume a larger quantity of commercial energy, while the group comprising marginal and small farms, and landless agricultural laborers tend to consume a larger quantity of noncommercial energy. It is, therefore, of interest to understand the occupation-wise distribution of the population in the study area.

[1] Size of farms are classified on the basis of land holdings, i.e., marginal farms up to 1.00 ha, small farms=1.01–2.00 ha, medium farm=2.01–4.00 ha, and the large farms=4.01 ha and above area of land holding.

Fig. 4 shows the percentage of workers in each farm size category. The figure also reveals that the percentage of workers having agriculture as their primary occupation steadily increases with size of the farm, while that of workers also having a secondary occupation steadily decreases with increasing farm size.

4.4. Operational holding

Agriculture being the major source of income in the study area, the size of the operational holdings is an important parameter, which determines the demand and supply of energy, the distribution of energy consumption type-wise, such as, human, animal, farm yard manure (FYM), fossil fuel, chemical fertilizer, etc.; and also influence the use of different types of implements at the farms and household levels. Moreover, households having larger operational holdings are found to consume a larger quantity of energy while the reverse is the case with households having marginal operational holdings. It has been observed during the survey that some of the landowners in the hilly zone of the study area reside in the town areas and control their land through tenancy and collect rent from their tenants. The size of the operational holdings is determined by the total area of own land, and leased-in land. Leased-out land, if any, is subtracted from the above for arriving at the size of holdings. The distribution of operational holding of the household is presented in Fig. 1, and that the average size of marginal, small, medium, and the large farms is 0.40, 1.44, 2.71, and 5.00 ha, respectively. Average size of holdings for all farms is 0.77 ha. The relative proportions of own land, leased-in land, and leased-out land are 83.12, 18.18, and 1.3%, respectively.[2] Own land constitutes the major part of the operational holdings for all farm sizes, and contributes 85.00, 79.86, 86.71, and 100% for marginal, small, medium and large farms respectively. Of the total oper-

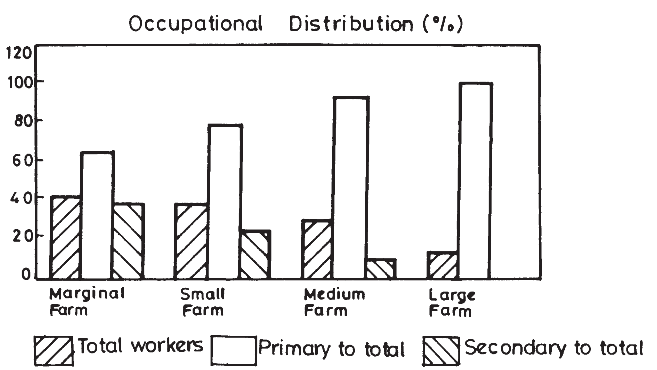

Fig. 4. Holding sizewise occupational distribution.

[2] The difference in leased-in and leased-out land is due to the fact that owners leasing out their holdings are not proportionately covered in the sample survey. In fact, most such owners reside in rurban areas outside the area targeted in the survey.

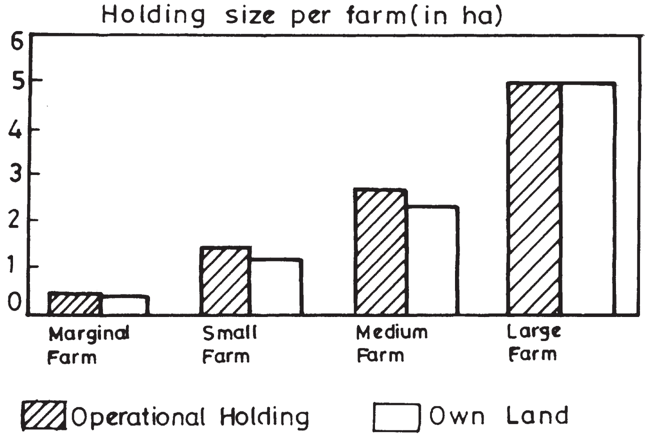

Fig. 5. Farm sizewise-operational holding and own land.

ational holdings, leased-in land constitutes 15.00, 21.53, and 17.34%, respectively for marginal, small, medium farms. Leased-out land forms only an insignificant part, and is restricted to 1.38 and 4.05%, respectively for small and medium farms only.

Fig. 5 shows the operational holding and own land for different farm size categories and reveals that the operational holdings for marginal, small and the medium farm categories are larger in area than their own land area.

4.5. Value of farm assets

Although the value of the farm assets is not directly linked with energy consumption, data about the nature and extent of investment was collected to determine the economic status of the households. The value of the assets of a farm was taken to be the investment on land, livestock, poultry, farm machinery, and farm implements. Details of farm assets for various sizes of farms are given in Fig. 6. The value of

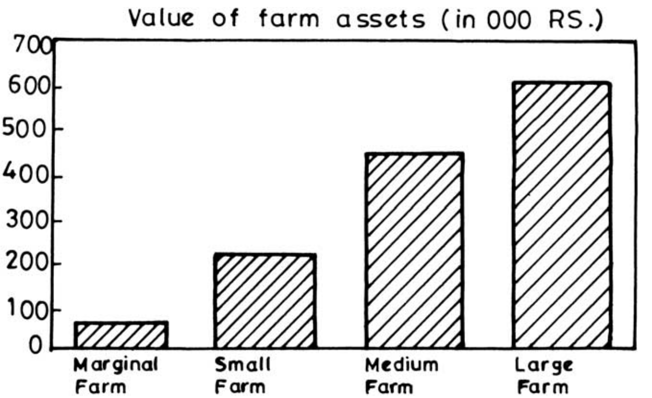

Fig. 6. Average value of farm assets.

the land constitutes the major part of the total assets for all categories of the farm, and the share of the livestock, poultry, and farm implements is small.

4.6. Bovine resources

Bovine resources are one of the more important sectors in an agrarian economy, which consumes energy on one hand, and produces energy on the other. The quantity of energy intake and output vary with the type of livestock. The livestock population has been classified into various categories for identifying the energy intake and output for different types of animals.

In this study, the livestock population was classified into three groups: cattle, goats and sheep, and poultry, the cattle population being further categorized in working, milch and other animals. The total availability of bovine resources are presented by different size of farms in Fig. 7, and the farm size wise availability of cattle, such as, working, milch, other animals, and goats and sheep, and poultry are presented in Fig. 8, and they show that the use of working cattle is the largest in the marginal farms, followed by medium farms. The population of milch, other animals, goats and seeps, and poultry are the highest in the marginal farm category.

4.7. Cropping pattern

Cropping pattern is one of the prime factors which determine the energy demand and supply pattern at the farm level. It has been observed that the field crops consume relatively larger quantity of energy and produce relatively smaller quantity of energy in the form of crop residues, etc. On the other hand, plantation crops consume relatively smaller quantity of energy but produce larger quantity of energy in the form of fuelwood, kernels, husk, fiber, etc. Field crops require a larger quantity of energy

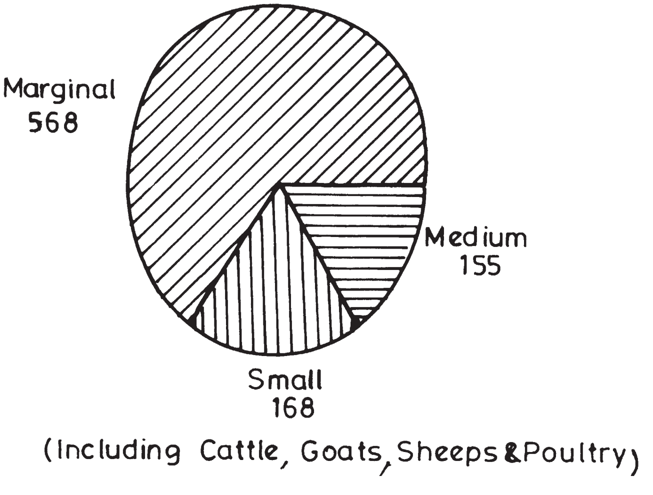

Fig. 7. Bovine resources (farm sizewise).

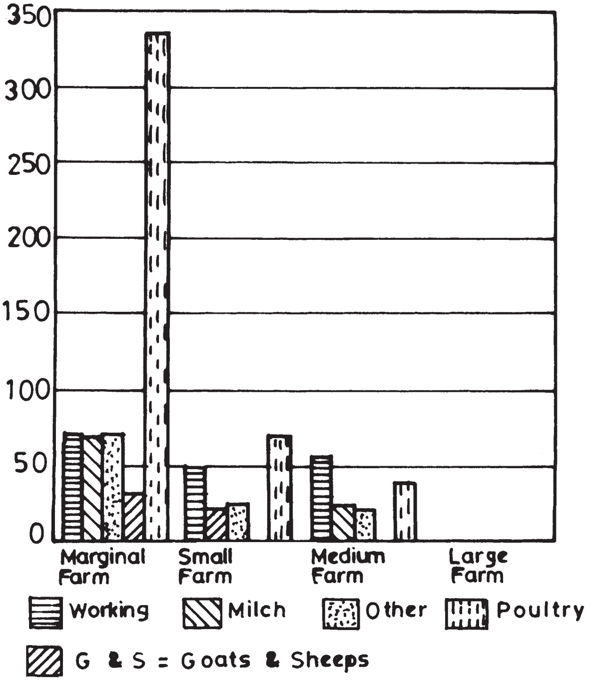

Fig. 8. Bovine resources (farm sizewise).

in the form of chemical fertilizers, and for irrigation, and crop management in comparison with plantation crops. Hence, it is essential to ascertain the coverage of area under different types of crops for proper quantification of energy consumption and production. In the study area, the major field crops are paddy and tapioca, while coconut and tamarind are the major plantation crops.

4.7.1. Field crops

The major field crops, paddy and tapioca cover 92.42 and 7.58%, respectively of the total cropped area. Of this, the share of paddy ranges from 83.78 to 100% from marginal to large farm categories.

4.7.2. Plantation crops

Of the two major plantation crops grown in this area coconut occupies 81.82%, while tamarind occupies 18.18% of area on an average for all farm categories. The area under coconut ranges from 33.33 to 100% for marginal to large farms, while area under tamarind is 66.67, 7.69, and 23.91% for marginal, small, and medium farms, respectively.

4.8. Cropping and irrigation intensity

Cropping intensity is another important factor which determines the energy requirement in agricultural operations. In the study area, the field crops are cultivated in one, two or three seasons depending upon the infrastructure facilities. For a farm cultivating field crops in more than one season, the energy demand and supply would increase accordingly.

Irrigation is one of the factors of prime importance in Indian agricultural system. Energy consumption for irrigation purely depends on the nature of the water source and the irrigation methods employed. While the direct flow method of irrigation requires only a relatively small quantity of energy in the form of manpower. Installation of electrified and dieselised pump sets leads to an increased consumption of commercial energy. Since, the choice of the method of irrigation is guided by the nature of the water source and the irrigation requirement for the crops; different sources and frequency of irrigation in the study area were also covered by the survey. The major source of irrigation in the study area is canals, rivers, and ponds.

For the present study, cropping intensity has been defined as the ratio of the gross cropped area to the net sown area, where the former is the sum of the net sown area and the area covered by a crop in the second season. The cropping and irrigation intensity for different farm sizes is shown in Fig. 9. It can be seen that the cropping and irrigation intensities are very closely related in the study area.

4.9. Yield of crops

Fig. 10 shows the variation of crop production of four crops namely, paddy, tapioca, coconut, and tamarind for different farm categories. The productivity of tapioca in small farms is larger than that in marginal farms. The productivity of paddy and coconut appeared to be comparable in the marginal, small and medium size farms. However, for the large farm, the productivity of coconut seems to be lower. Paddy and tamarind production was found to decrease with increase in size of farms, while

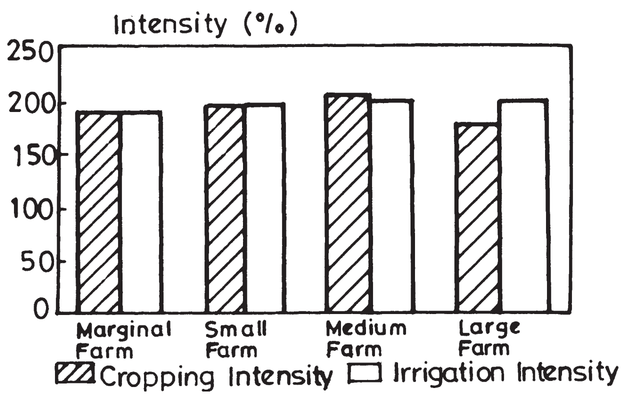

Fig. 9. Cropping/irrigation intensity.

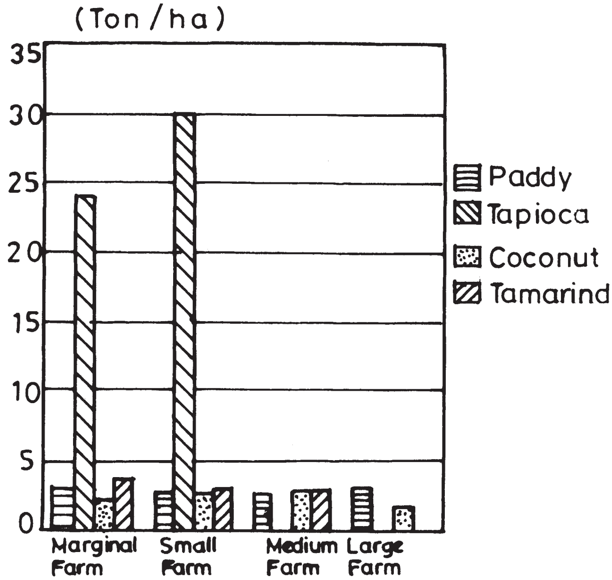

Fig. 10. Crop production (farm sizewise).

production of coconut and tapioca was found to increase with increase in farm size. In arriving at these observations, the yield of large farm category has not been considered since the size of the sample in this category is very small.

4.10. Crop residues

The ratio of the main product to the by-product varies due to difference in verities, cultivation practices, and application of different types of technologies at the farm level. The main crops in the study area are paddy, coconut, tapioca and tamarind, and the corresponding characteristic data for these are compiled. The ratio for crop residues is calculated on the basis of the production of the main products and their by-products for analysis. The source-wise and farm size wise total quantity of the crop residues production is presented in Fig. 11(a) and (b), respectively, which reveal that the quantity of paddy straw production is very high among the cereal crop residues, and constitutes the major feed to bovine resources in the study area.

4.11. Energy consumption for agricultural operation

In the study area, draught animal powered plough is the main technology used for land preparation. Hence, human labor and draught animal power are the only sources of energy used in this regard.

Energy consumption for land preparation for agricultural operation is calculated on the basis of total human and animal labour used per hectare of land. The quantity of both human and animal labor energy used in this regard illustrates that for

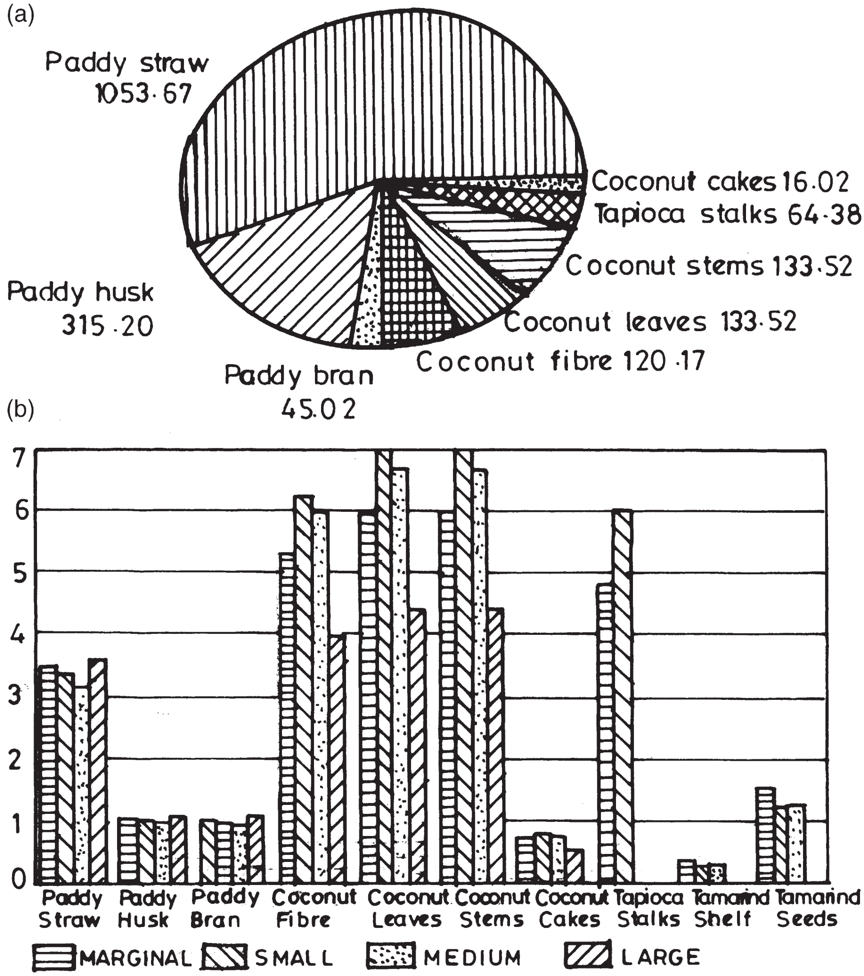

Fig. 11. (a) Total quantity of crop residue production. (b) Crop residue production (farm sizewise).

operating a hectare of land, 150 man-days of human labour and 38 pair-days of draught animal power are the only sources of energy required.

4.11.1. Energy consumption for irrigation

Energy consumption for irrigation is calculated for different sources of irrigation, such as, canals, tanks, and ponds and the total number of man-days, animal-days, machine-days, and diesel and electricity required for lighting a hectare of land. Since canals, tanks, and ponds are the major sources of irrigation in this study area, human labor is the only sources of energy used for irrigation and it is found that for irrigating a hectare of land 49 man days of work was used in the study area.

4.11.2. Fertilizer application

The intensity of application of organic and inorganic fertilizers presented in Fig. 12, and it shows that the percentage share of organic fertilizers increases from 70.57 to 76.58% from marginal to large farms, while application of organic fertilizers decreases from 29.43 to 23.42%. The average figures for all farms, are 71.51 and 28.49% for inorganic and organic fertilizers. Fig. 12(b) shows the consumption of organic and inorganic fertilizers for different farm sizes.

4.12. Energy consumption for cattle rearing

Human energy consumption for rearing and maintenance of working, milch and other cattle is estimated to be 45.62, 91.25, and 45.62 man-days per annum respect-

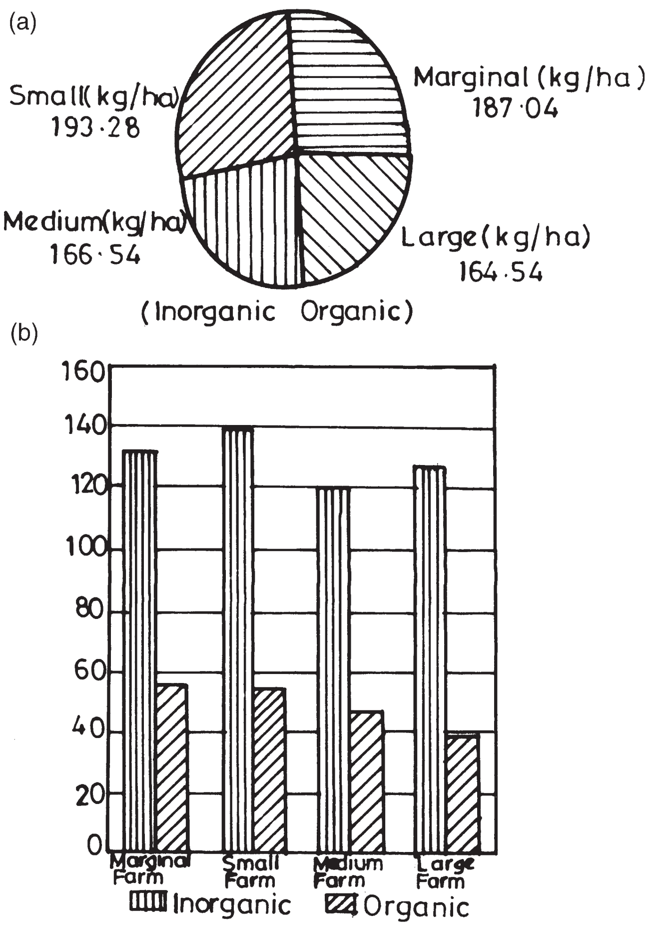

Fig. 12. (a) Application of fertilizers. (b) Fertilizer application (farm sizewise).

ively. It is clear that the maintenance of milch animals requires more man power than that for other categories of cattle.

4.13. Energy consumption for services

Resources requirement for services can be calculated on the basis of mode of transportation and the type of energy sources used for services. In the study area bullock carts are mainly used for transportation, and thus make use of animal and human energy, which can be quantified on the basis of transporting a ton of goods or a number of persons over a distance of 1 km.

4.14. Household energy consumption

4.14.1. Cooking

The design of the cooking stove is one of the major factors which governs cooking energy consumption. Fuel-efficient cooking stoves require less than half of the energy compared to conventional stoves. In addition, application of liquefied petroleum gas (LPG) stoves, and biogas stoves where possible would reduce the dependence on fuelwood, resulting in cumulative beneficial impact by retarding deforestation and minimizing ecological imbalance in the rural areas. The study aims at to identify the extent of different types of stoves used for cooking, and finds an increasing share of these improved techniques in the households possibly due to a higher educational levels prevalent in the study area.

The marginal farms use 76.2 and 62.38%, respectively of the mud and kerosene stoves in this area. Use of biogas stove ranges from 66.67 for the households in the small farm category to 33.33% for medium size households. Also nearly 55% of households in the large farm category use the LPG stoves. The shift from dependence on fuelwood and kerosene for the low-income groups towards LPG stoves for the higher income group can be clearly seen.

Fig. 13 shows the total quantity of cooking energy consumption derived from different sources of energy for households belonging to different farm sizes. Energy consumption for cooking for households in the marginal, small, medium, and the large farms categories is 4598, 5333, 4552, and 5504 MJ per capita per year respectively, while the average for all farms is 4733 MJ per capita per year.

4.14.2. Lighting

Kerosene and electricity are mainly used for lighting in the study area. Tamil Nadu is one of the first states in India to provide electricity supply to all of its villages. The Government of Tamil Nadu had introduced a free electricity scheme for the provision of electricity supply facilities to the downtrodden communities of the State. Accordingly, the people residing in the huts became eligible to get electricity by paying a meager amount of Rs. 5.00 per month. As a result, most of the rural huts at the present time enjoy these facilities in the State. However, a section of poor people residing in tiled roofed huts is not eligible for electrical connection via this scheme, and they mainly use kerosene lights.

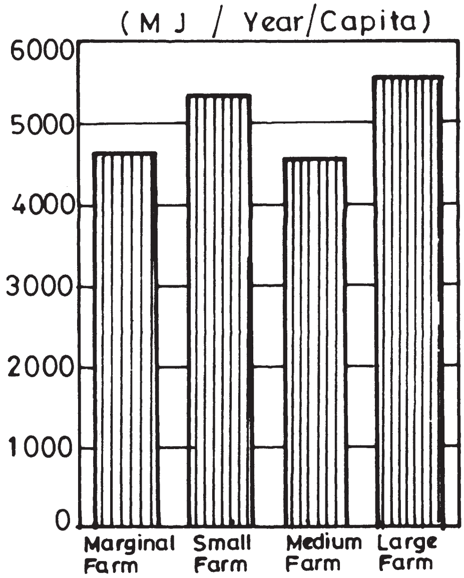

Fig. 13. Cooking energy consumption (farm sizewise).

4.14.3. (a) Kerosene lights

Though all the villages are having electric connections in the study area, a sizable fraction of the poorer people still use kerosene lamps for lighting. The use of open and closed chimney lamps by the different size of farms is analyzed, showing that the use of open chimney lamps decreases with increase in the size of farms for marginal to large farms, i.e., from 79.61 to 0.28%. A similar trend is observed for lamps with closed chimney, but a larger number of open chimney lamps are used in comparison with closed chimney lamps in all farm sizes. It indicates that the usage of closed chimney lights is predominant in the economically poor section of the people, since they can not offer to invest in electric lighting facilities in their houses.

4.14.4. (b) Electric lights

Households that are economically slightly better off tend to use a larger number of fluorescent tube lights. Different types of electric lights used at the households are analyzed and it illustrates that the number of electric lights per household increases with size of farms from 6.4 for marginal farm to 12.9 for medium farm. It is also observed that more effluent households belonging to the large farm size use a larger fraction of fluorescent lights in contrast with incandescent lamps.

Energy consumption for lighting for households in different farm sizes is presented in Fig. 14. Consumption of kerosene is seen to decrease with the increase in the size of farms. The annual per capita consumption of kerosene is seen to be 1.55, 0.64, 0.51, and 0.44 liters, respectively for marginal, small, medium and large farms. The annual per capita consumption of electricity increases with form size, and is seen to vary from 49.02, 100.03, 122.11, to 153.33 kWh for marginal, small, medium, and

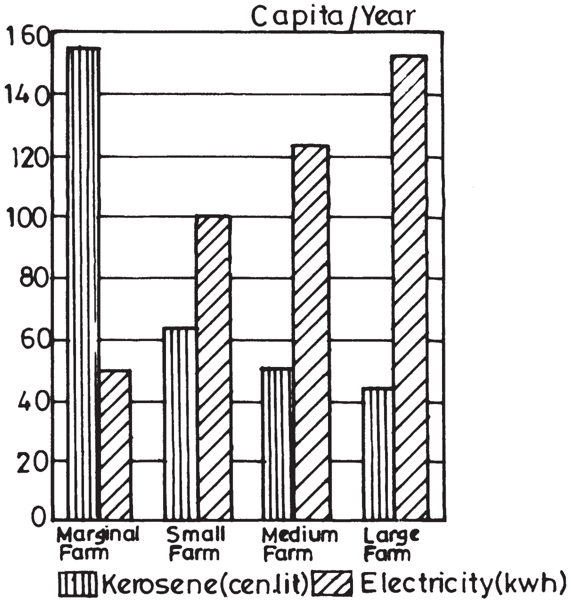

Fig. 14. Energy consumption for lighting (farm sizewise).

large farms respectively, and for all farms the annual per capita use of kerosene and electricity are 1.3 liters and 63.94 kWh, respectively, mainly used for illumination.

4.15. Comparison of secondary and primary data

Some important parameters which have significant influence on consumption, supply and demand of energy in the study area as available from secondary and primary data are compared. Distinct variations have been found in some parameters and they are discussed in the sequel.

Figs. 15–20 illustrate the considerable differences between data obtained from the primary survey and the secondary sources. Fig. 15(a) and (b) show the percentage

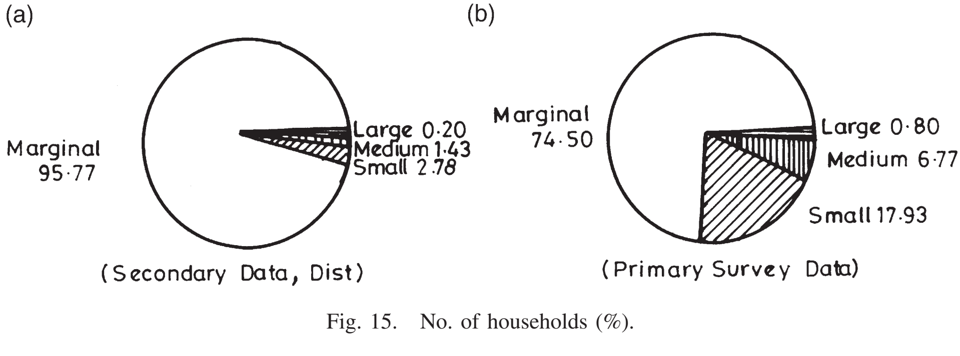

Fig. 15. No. of households (%).

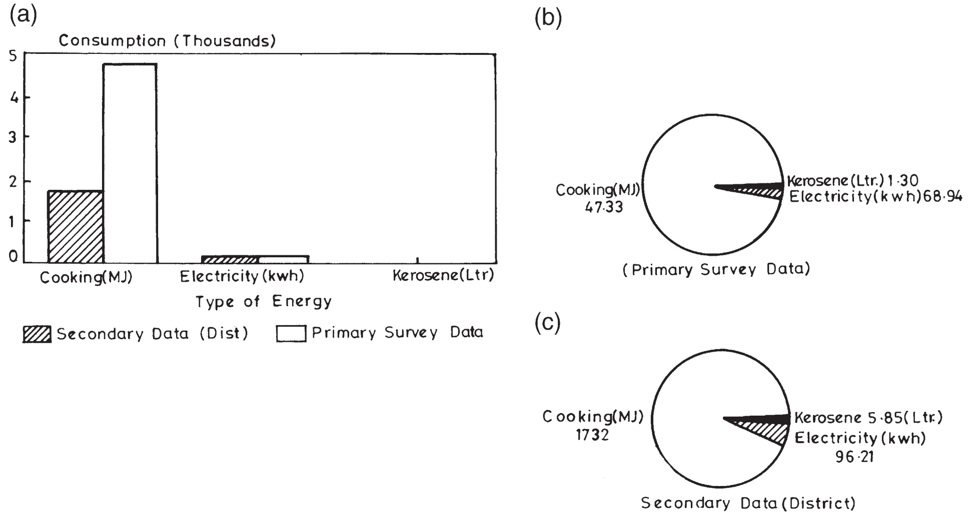

Fig. 16. Household energy consumption (percapita/annum).

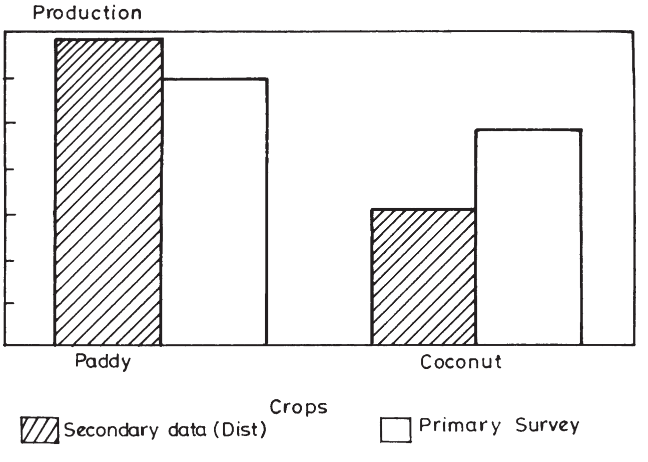

Fig. 17. Crop production (ton/ha).

households belong to different farm size categories. The discrepancy between the two sets of data is due to the fact that in primary survey the households not possessing the agricultural land was excluded from the survey, while households from the categories are included in the marginal farm category boosting their percentages since the energy consumption based on primary and secondary data would be quite divergent.

Fig. 16(a)–(c) show the household energy consumption for cooking and lighting and reveal a considerable difference between the primary and secondary data. The annual per capita cooking energy consumption is 1732 MJ as per the secondary sources, but was estimated to be 4733 MJ from survey data. Recently published data

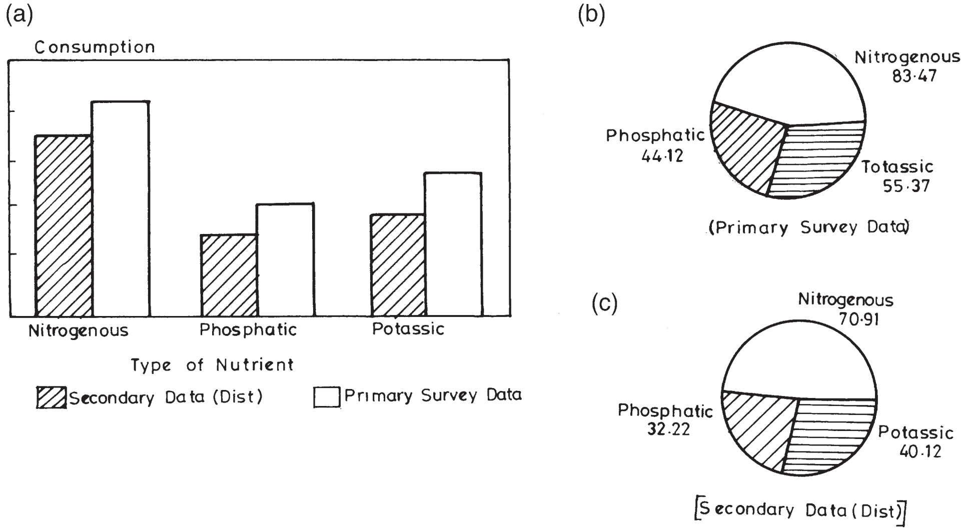

Fig. 18. NPK consumption (kg/ha).

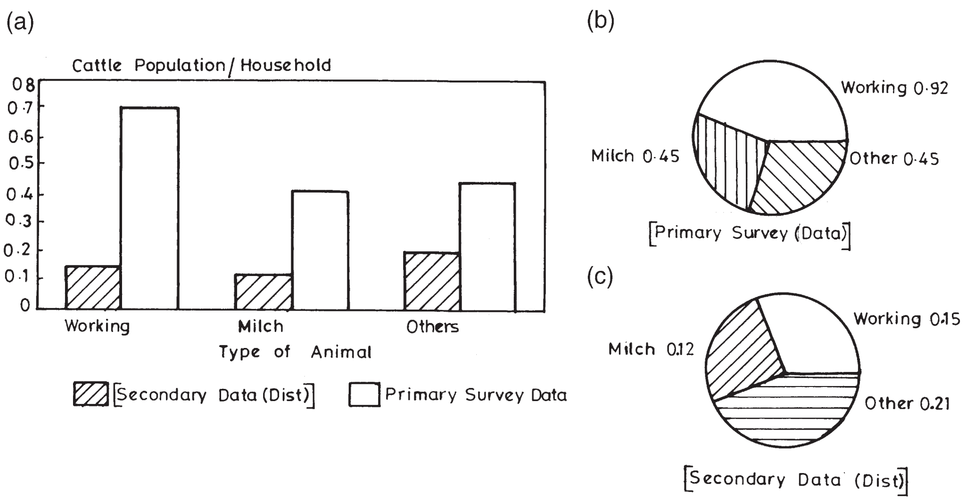

Fig. 19. (a) Cattle population. (b) (c) Cattle population per household.

(1992) [4] reveals that the annual per capita cooking energy consumption in rural Tamil Nadu is 5895 MJ. The increase in cooking energy can be attributed to rise in per capita income in the area leading to corresponding increase in energy consumption.

Fig. 17 shows the productivity of paddy and coconut crops based on primary and secondary data. It is seen that paddy productivity has gone down while that of coconut has gone up considerably in the primary survey. The slight reduction in pro-

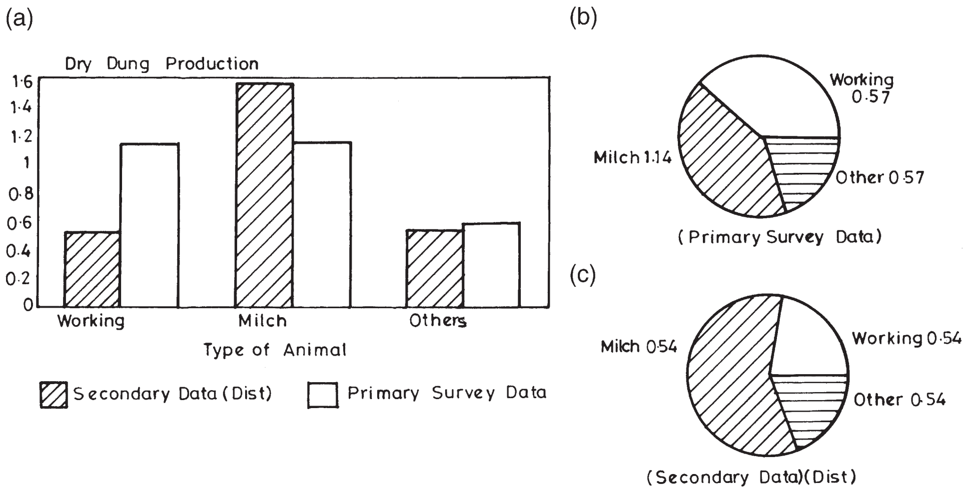

Fig. 20. Dry dung production (ton/annum/animal).

ductivity of paddy is possibly due to slight reduction in the cropping and irrigation intensity in smaller size farm whose percentage has increased during the period corresponding to the time lag between collection of secondary and primary data. Similarly the increase in coconut productivity in the primary survey data represents steady improvement in the increased area under the hybrid variety and greater case of fertilizers in plantations. The above conclusion also showed in Fig. 18(a)–(c). The difference in plant nutrient consumption between primary and secondary data which can be attributed to the increase during the intervening period between the two surveys.

Fig. 19(a)–(c) show the considerable difference in the cattle population per households as per primary and secondary data. The considerable increase in the cattle population in each category is due to the time lag and the intensive inputs in cattle rearing program in the study area. Fig. 20(a)–(c) show the considerable difference in dung production as per primary and secondary data in the study area. The considerable increase in dung production in each category in general is due to special attention to dairy development programs as the part of the poverty alleviation programs since 1980’s in the target area.

4.16. The rural system model

A rural system has several interacting subsystems, which inter-linked, and interdependent in several ways. In a given rural system, a subsystem’s output, in general, has multiple usages, and thus forms the input to one or more subsystems resulting in a system possessing a complex structure. The major subsystems and their inputs and outputs are briefly discussed below:

4.16.1. Households

The subsystem, Households, obtains energy from Households, Agriculture, and Livestock in the form of human labour, food and animal power, while supplying energy input in the form of human labour to all other subsystems.

4.16.2. Agriculture

The subsystem, Agriculture, obtains energy from different subsystems, such as, Household, Livestock, and Rural Transport, in the form of human labour, animal power, farm yard manure. It also receives energy, in the form of electricity, diesel, and chemical fertilizers from outside the system, while producing food, and non-food items, crop residues, fodder, timber, logs, fuelwood, etc. which contribute inputs to various subsystems.

4.16.3. Livestock

The subsystem, Livestock, obtains energy from Household, Agriculture, Transport, and from itself in the form of human labour, animal power, crop residues, fodder, feed, etc., while it produces milk, cattle dung, and drought power forming inputs to other subsystems like Household, Agriculture, and Rural Transport.

4.16.4. Rural Industry

The subsystem, Rural Industry, obtains energy from different subsystems, such as, Household, Agriculture, Livestock, Rural Transport, in the form of human labour, animal power and industrial inputs (Agricultural output—both major products and byproducts). It also receives energy, in the form of electricity, diesel and kerosene from outside the system, while producing output which contribute inputs to various subsystems.

4.16.5. Rural Transport

The subsystem, Rural Transport, mainly serves two subsystems—Household, and Agriculture, and draws its major inputs, i.e., drought power from the subsystem Livestock and manual power from the subsystem Households.

It may be noted that in this present study, the subsystem Rural Industries has been excluded, since the study area is one of the more industrially backward districts, and the economy of the district is mainly dependent on agriculture and allied activities. Also none of the sample households covered by the survey indicated the existence of even small industrial units in this rural area.

The interrelationships and interactions for various subsystems of the rural system are shown in Fig. 21.

4.17. Technical coefficients, model inputs and outputs

For arriving at quantitative results for the rural systems model, the primary data was processed and classified into two categories, (i) technical coefficients, and (ii) input data for the base run and for future projections. An overview of the relation-

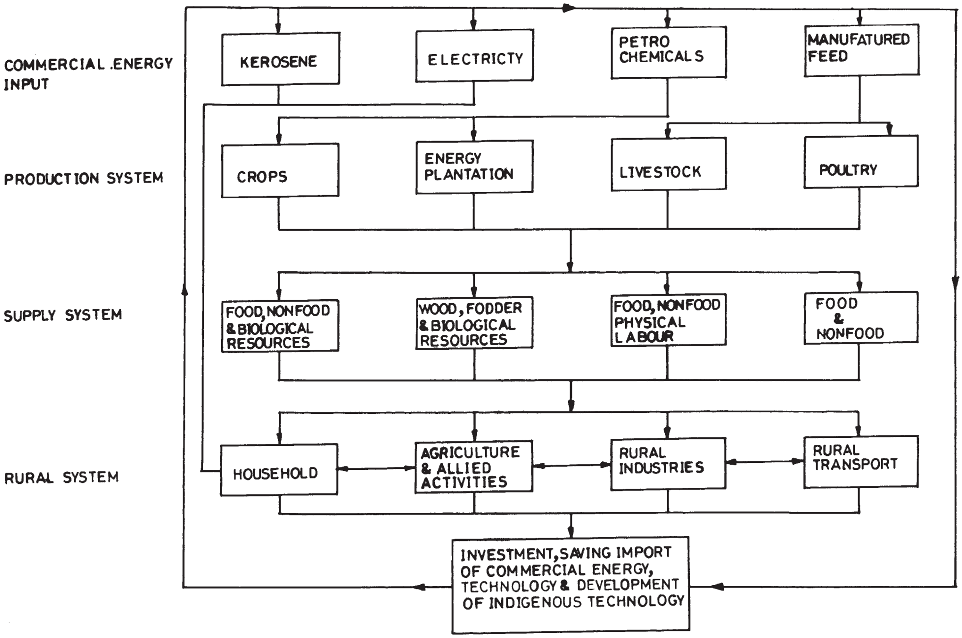

Fig. 21. Dynamic functions of the rural system with energy related interaction.

ships between the inputs, the technical coefficients, and the outputs for the rural systems model is shown in Fig. 22.

4.17.1. Technical coefficients

The technical coefficients may be visualized as model parameters which relate the model variables. Some of the technical coefficients like energy contents of different types of fuels, etc., are constants, while others are variables which may be considered to be constants over a limited span of time under a given set of conditions. For example, crop and crop residues production, feed and nutrient contents of crop residues, inputs to and outputs from livestock, etc. remain constant when the agricultural practices and the crop or livestock varieties are unchanged. In the present study, some of the technical coefficients were calculated on the basis of survey data, while the others were derived from data available in literature.

The technical coefficients obtained on the basis of secondary data available in literature [2,3] are: (1) nutrient contents of crop residues; (2) feed contents of crop residues; (3) nutrient contents of bought feeds; (4) nutrient content of farm yard manure; and (5) energy content of different fuels and efficiency of different devices. These technical coefficients are given in Tables 1–5.

The technical coefficients calculated on the basis of the survey data are: (1) yield of crops; (2) crop residues ratio to crop production; and (3) input to and output of cattle; (4) specific energy consumption for crop production; (5) specific energy consumption for irrigation; (6) intensity of inorganic fertilizers application; (7) inten-

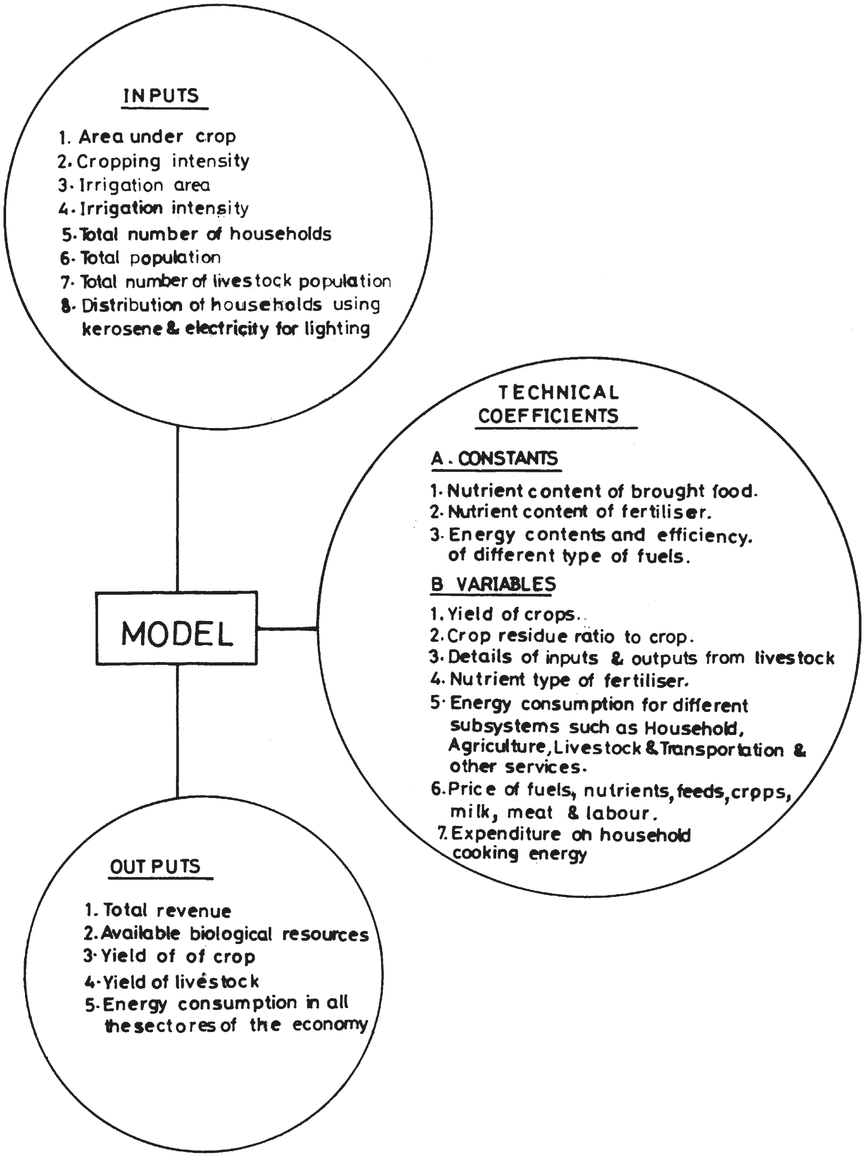

Fig. 22. Inputs and outputs of the rural energy system model.

sity of organic fertilizers application; (8) specific energy consumption for cooking; (9) specific energy consumption for lighting; (10) specific human energy consumption for cattle rearing; (11) specific energy consumption for services, and are given in Tables 6–16.

Table 1
Nutrient content of crop residues[a]

SI. No.	Types of crop residues	N_2	P_2O_5	K_2O
1.	Tapioca stalks	7.1	1.5	5.8

[a] Source: [3, pp. 181–92].

Table 2
Feed content of crop residues (ton/ton dry)[a]

SI. No.	Types of crop residues	DCP	TDN
1.	Paddy straw	0.010	0.48
2.	Paddy bran	0.088	0.61
3.	Coconut cakes	0.417	0.80
4.	Tamarind seeds	0.157	0.91
5.	Tapioca stalks	0.069	0.63

[a] Source: [3, pp. 181–92].

Table 3
Nutritional content of bought feeds (ton per ton)[a]

SI. No.	Type of feeds	DCP	TDN
1.	Paddy bran	0.088	0.61
2.	Tamarind seed	0.157	0.91
3.	Cotton seed	0.157	0.91
4.	Groundnut cake	0.417	0.80

[a] Source: [3, pp. 181–92].

Table 4
Nutrient content of farm yard manure (cattle dung) (in %)[a]

SI. No.	Type of fertilizer	N_2	P_2O_5	K_2O
1.	Dung (kg/ton)	9	6	11
2.	Biogas sludge (kg/cum)	0.016	0.0143	0.01

[a] Source: [3, pp. 181–92].

4.17.2. Model inputs and outputs

The variables constituting the inputs to the rural system model (RSM) are: area under crops and cropping intensity; area under irrigation and irrigation intensity; total number of households; total population; total cattle population; data about usage of kerosene and electricity for lighting; prices of fuels, nutrients, crops, milk, meat,

Table 5
Energy contents and efficiency of different types of fuels[a]

SI. No.	Types of fuel	Primary energy (kcal/kg)	Cook-efficiency (%)
1.	Paddy husk	3440	11.1
2.	Coconut husk	2816	11.1
3.	Coconut stems	4296	11.1
4.	Tamarind shells	4296	11.1
5.	Tapioca stalks	4296	11.1
6.	Dung	3300	9.0
7.	Fuelwood (*h*)	3510	11.1
8.	Fuelwood (*f*)	4700	12.5
9.	Fuelwood (*p*)	4700	12.5
10.	Soft coke	5780	17.7
11.	Biogas	4300	55.0
12.	LPG	10300	60.0
13.	Kerosene	8647	42.4
14.	Electricity	860	53.8

[a] Source: [2].

Table 6
Crop yield (ton/ha)

SI. No.	Size of farms	Type of crops			
		Paddy	Tapioca	Coconut	Tamarind
1.	Below 1.00	3.00	23.83	2.36	3.78
2.	1.01–2.00	2.90	30.00	2.75	3.10
3.	2.01–4.00	2.70	–	2.65	3.00
4.	4.01 and above	3.10	–	1.77	–
	All farms	2.96	23.13	2.44	3.57

and labour. A representative set of model inputs for the sample farms for the base year 1989 are given in Tables 17–21, and the outputs are presented in Table 22.

4.18. Model validation and application

In order to examine the validity of the model the salient results obtained from a run of the model were compared with the survey data. The computed values from the model and the corresponding figures from the survey data are given in Table 23, and illustrate that there is little difference between the survey data and the generated from the model. As per the survey data, 45.67% of the total digestible crude protein (DCP) is obtained as input to the system from outside, but in the model, the requirement of DCP is met from within the system. This difference was considered to be

Table 7
Crop residue to crop ratio (ton per ton)

SI. No.	Type of crop residues	Type of crops			
		Paddy	Coconut	Tapioca	Tamarind
1.	Paddy straw	1.17	–	–	–
2.	Paddy husk	0.35	–	–	–
3.	Paddy bran	0.05	–	–	–
4.	Coconut fibre	–	2.25	–	–
5.	Coconut leaves	–	2.50	–	–
6.	Coconut stems	–	2.50	–	–
7.	Coconut cakes	–	0.30	–	–
8.	Tapioca stalks	–	–	0.20	–
9.	Tamarind shells	–	–	–	0.10
10.	Tamarind seeds	–	–	–	0.40

Table 8
Inputs and outputs from livestock (per cattle/year)

SI. No.	Catgories	Units	Type of animals		
			Working	Milch	Others
1.	Milk output	kl	–	0.81	–
2.	Dung output	ton	1.14	1.14	0.57
3.	TDN consumption	ton	1.23	1.29	1.20
4.	DCP consumption	ton	0.05	0.09	0.06
5.	TDN grazing	(%)	0.01	0.01	0.01
6.	DCP grazing	(%)	0.01	0.01	0.01
7.	Fraction of dung collected	(%)	0.80	0.90	0.90

Table 9
Specific energy consumption for crop productions

SI. No.	Types of labour	Total no. of days
1.	Human labour	150
2.	Animal labour (pair)	38

Table 10
Specific energy consumption in irrigation (no. of days/ha)

SI. No.	Types of energy	Sources of irrigation		
		Canals	Tanks	Ponds
1.	LBIR[a]	20	4	25

[a] LBIR=manual labour days.

Table 11
Specific consumption of inorganic fertilizers (kg/ha)

SI. No.	Size of farms (ha)	Nitrogenous	Phosphatic	Potassic
1.	Below 1.00	66	33	33
2.	1.01–2.00	67	36	36
3.	2.01–4.00	58	31	31
4.	4.01 and above	60	33	33
	All farms	64.14	33.49	33.49

Table 12
Specific consumption of organic fertilizers (kg/ha)

SI. No.	Size of farm (ha)	Nitrogenous	Phosphatic	Potassic
1.	Below 1.00	20.97	11.04	23.03
2.	1.01–2.00	20.40	11.18	22.70
3.	2.01–4.00	17.23	9.41	19.28
4.	4.01 and above	13.33	–	16.33
	All farms	19.73	10.63	21.88

Table 13
Specific energy consumption for cooking (MJ/year/capita)

SI. No.	Size of farms (ha)	Quantity
1.	Below 1.00	4598.00
2.	1.01–2.00	5333.00
3.	2.01–4.00	4552.00
4.	4.01 and above	5504.00
	All farms	4733.00

Table 14
Specific energy consumption in lighting (capita/year)

SI. No.	Size of farms (ha)	Kerosens (liters)	Electricity (kwh)
1.	Below 1.00	1.55	49.02
2.	1.01–2.00	0.64	100.03
3.	2.01–4.00	0.51	122.11
4.	4.01 and above	0.44	153.33
	All farms	1.30	63.94

Table 15
Specific human energy consumption for cattle rearing (mandays/year)

SI. No.	Types of cattle	Human energy
1.	Working	45.62
2.	Milch	91.25
3.	Others	45.62

Table 16
Specific energy consumption for services (transportation) (days/ton/km)

SI. No.	Type of resources	Animal (bull)	Tractor	Truck	Human (cycles)
1.	LBTR[a]	0.17	0.0	0.0	0.0
2.	ANTR[b]	0.08	0.0	0.0	0.0

[a] Manual labour days.
[b] Animal labour days (pair).

insignificant for the present study, and consequently, the model was taken to adequately represent the reality of the rural system.

This model has been applied to quantify the resources and the energy consumption pattern in different subsystems of the system for the rural segment of the district. The results of the model show that from the year 1989, the total production of paddy, tapioca, coconut and tamarind was 129 960, 194 430, 36 970, and 6740 tons, respectively. Total available quantity of crop residue was 1 763 000 tons, dung was 123 000 tons, and fuelwood was 24 000 tons. The total quantity of energy consumption for cooking was 266 209 tons of fuelwood with 11% fuel efficiency (527 088 GJ). The total consumption of DCP was 10 880 tons, and the total digestible nutrient (TDN) was 204 390 tons for livestock rearing. The total quantity of nitrogenous, phosphatic and potassic fertilizer application in agricultural activities was 8237, 4333 and 5438 tons, respectively. The results of the model are presented in Table 24.

Table 17
Major model inputs

SI. No.	Major inputs	Marginal farms	Small farms	Medium farms	Large farms	All farms
1.	Area under crop (ha./farm)	0.40	1.44	2.71	5.00	0.77
2.	Cropping pattern (ha/farm)					
	(a) Paddy	0.31	1.14	2.24	4.00	0.61
	(b) Tapioca	0.06	0.04	–	–	0.05
	(c) Coconut	0.01	0.24	0.35	1.00	0.09
	(d) Tamarind	0.02	0.02	0.11	–	0.02
3.	Cropping intensity (ha in %)	186.11	192.50	202.69	180.00	192.31
4.	Total irrigated area (ha/farm)	0.35	1.18	2.22	4.00	0.64
5.	Irrigation intensity (ha in %)	188.57	194.27	198.65	200.00	193.75
6.	Total number of households	187.00	45.00	17.00	2.00	251.00[a]
7.	Total population (no.)	930.00	218.00	85.00	9.00	1242.00[a]
8.	Total cattle population (no.)	201.00	93.00	99.00	–	393.00tfn[a]
9.	Households using kerosene and electricity for lighting:					
	(a) Kerosene (% of households)	12.00	–	–	–	9.00
	(b) Electricity (% of households)	88.00	100.00	100.00	100.00	91.00

[a] Denotes total numbers.

Table 18
Price of the crops (Rs/ton)

SI. No.	Types of crops	Rupees
1.	Paddy	2500
2.	Coconut (copra)	25 000
3.	Tamarind (seedless)	16 667
4.	Tapioca	1250

4.19. Objective function of the linear programming (LP) model

An overview of the rural system along with its major components and their interactions can be clearly discerned from Fig. 23. The objective of the LP model is the maximization of the revenue from crops and energy production subject to system constraints. The revenue generated in the rural system is obtained by subtracting the total cost of fertilizers, commercial energy, animal feed and wages for hired labour from the crop revenue, and it is chosen as the objective function for the model, and

Table 19
Price of milk, meat, feed and labour (Rs/unit)

SI. No.	Particulars	Units	Rupees
1.	Milk	(kl)	5000
2.	Meat	(ton)	15 000
3.	Feed	(ton)	3000
4.	Labour days	(1)	30

Table 20
Price of the nutrients (Rs/kg)

SI. No.	Types of nutrients	Rupees
1.	Nitrogen (N_2)	5.11
2.	Phosphorous (P_2O_5)	5.14
3.	Potash (K_2O)	2.17

Table 21
Price of fuel (Rs/kg/unit)

SI. No.	Types of fuel	Rupees
1.	Paddy straw	2.00
2.	Paddy husk	0.50
3.	Paddy bran	1.00
4.	Coconut husk	0.50
5.	Coconut leaves	1.00
6.	Tamarind shells	0.50
7.	Tapioca stalks	0.50
8.	Dung	0.20
9.	Fuelwood—homestead	0.50
10.	Fuelwood—forest	0.60
11.	Fuelwood—plantation	0.50
12.	Liquid petroleum gas (LPG)	4.34
13.	Kerosene	1.75
14.	Electricity	0.50

the optimization problem is expressed as (variables are defined in the Nomenclature in Appendix A):

$$\mathrm{Max}\sum_j\sum_j=\sum_j\left[\sum_c Y_{cj}L_{cj}P_c-\sum_n P_nB_n-\sum_k P_kB_{kj}-\sum_f P_fB_{fj}-W(H_j-H_{\mathrm{own}j})\right].$$

The objective function of the model must be maximized subject to a number of constraints, which are discussed below.

4.19.1. Miscellaneous constraints

4.19.1.1. Crop residue Crop residue is available only in harvest months. The crop residue production must be greater than the sum of crop residue utilization for feed, nutrients, households, and other purposes. Hence the constraint can be expressed as

$$\sum_m\sum_j(-Y_{cmj}L_{cmj}r_c+F^{\mathrm{r}}_{cmj}+N^{\mathrm{r}}_{cmj}+Q^{\mathrm{r}}_{cmj}+O^{\mathrm{r}}_{cmj})\leq 0$$

where m=1–12 and j=1–4. Also Q_1, the total use of crop residues for cooking by all income classes, can be described as an equality constraint:

$$Q_{1,}=\Sigma\Sigma\Sigma Q^{\mathrm{r}}_{cmj}$$

where c=1–4.

4.19.1.2. Animal feed The quantity of feed intake through pasture, purchasing, and crop residue must exceed the total requirement. Two distinct types of animal feed constraints have been used, namely, the DCP content and the TDN.

TDN is expressed as

$$-(\mathrm{nut})^{\mathrm{past}}-(\mathrm{nut})^{\mathrm{b}}-B^{\mathrm{f}}-(\mathrm{nut})^{\mathrm{r}}F^{\mathrm{r}}+\sum_b f^{\mathrm{nut}}_{\mathrm{b}}A_b\leq 0.$$

The DCP is expressed as

$$-(\mathrm{Prot})^{\mathrm{past}}-(\mathrm{Prot})^{\mathrm{b}}B^{\mathrm{f}}-(\mathrm{prot})^{\mathrm{r}}F^{\mathrm{r}}+\sum_b f^{\mathrm{pro}}_{b}A_b\leq 0.$$

4.19.1.3. Animal dung The total dung collected from animals must exceed the sum used for manure, biogas, and household cooking. Hence the constraint can be expressed as

$$\sum_j[-\Sigma(C^{\mathrm{d}}_b d_b A_{bj}+N^{\mathrm{d}}_j+e^{\mathrm{d}}_b Q^{\mathrm{db}}_j)+Q^{\mathrm{d}}_j]\leq 0.$$

Also, Q_2, the total availability of dung used for cooking by all sizes of forms, is given by

$$Q_2=\sum_j Q^{\mathrm{d}}_j$$

where j=1–4.

4.19.1.4. Fertilizer nutrients The sum of store-bought chemical fertilizer, farm-yard manure, crop residue, and biogas sludge used as nutrients must also exceed the total quantity of applied nutrients. Hence this constraint can be expressed as

$$\sum_n\left[\sum_c F_{ncj}-B^n_j-(\mathrm{nut})^{\mathrm{d}n}N^{\mathrm{d}}_{nj}-(\mathrm{nut})^{\mathrm{r}n}N^{\mathrm{r}}_{nj}-N^{\mathrm{b}}_{nj}\right]\leq 0$$

where n=1–3 and c=1–4. It may be noted that in the above equations the three types

of nutrients, i.e., N, P, and K, have been included by letting n take the values n=1, 2, and 3.

4.19.2. Energy-related constraints

4.19.2.1. Household cooking The energy content of the energy source k used for cooking must exceed the total quantity of the useful energy requirement for cooking for households falling under each farm size j. Hence this constraint can be obtained as

$$\sum_k(-u_kQ_{kj}^{ck}+u_{kj}^{ck})\leq 0$$

$$\sum_j Q_{kj}^{ck}=Q_j^{ck}$$

where k=1–11 and j=1–4.

4.19.2.2. Lighting The energy content of the energy source k used for lighting must exceed the demand for lighting for the households falling under each farm size j. Hence this constraint can be expressed as

$$\sum_k(-u_kQ_{kj}^{1})+u_j\leq 0$$

$$\sum_j Q_{bj}^{1}=Q_b^{1}.$$

4.19.3. Energy budget constraints for households for cooking and lighting

For the households in each category j, the product of the per unit price P_k of energy type k and the quantity of this energy source used for cooking and lighting must be less than or equal to the household budget b^{h} for fuel and electricity. Hence

$$\sum_j P_k(Q_{kj}^{ck}+Q_{kj}^{1})\leq b_j^{\mathrm{h}}.$$

4.19.4. Energy constraints for different energy sources

4.19.4.1. Wood The quantity of wood obtained from homesteads (Q_3) cannot exceed a specified amount Q_{a}. The quantity of wood obtained from forests and plantations (Q_4 and Q_5, respectively) must be less than the yield (Y_{f} and Y_{p}, respectively) of the forest F and plantation P areas. Hence this constraint can be expressed as

$$Q_3\leq Q_{\mathrm{a}}$$

$$Q_4\leq Q_{\mathrm{f}}F$$

$$Q_5\leq Y_{\mathrm{p}}P.$$

The energy content of wood drawn from different sources, such as homesteads, plan-

tations, and forest must exceed the total quantity of wood energy actually used. Hence

$$\sum_k Q^c_{kj} \leq \sum_k Q_k$$

where k=1–3.

4.19.4.2. Biogas The total quantity of biogas produced from dung is equal to the biogas used for cooking by the households falling in the jth farm size. Hence the constraint can be

$$Q^{ab}_j = Q_{7j}.$$

Since the biogas in the study area is obtained entirely from dung, and the slurry of the biogas is used as manure, the use of cattle dung is governed by this constraint implicitly.

4.19.4.3. Natural gas The quantity of household cooking gas (liquefied petroleum gas) used in less than or equal to the purchased quantity. Hence the constraint can be expressed as

$$-B_{ng} + \sum_j Q^{ci}_9 \leq 0.$$

4.19.4.4. Kerosene The total quantity of kerosene used for household cooking and lighting must be less than or equal to the store-bought quantity. Hence the constraint can be expressed as

$$-B_k + \sum_j (Q^c_{10j} + Q^{11}_{10j}) \leq 0.$$

4.19.4.5. Electricity The total quantity of electricity consumption is equal to the store purchased quantity. Hence the constraint can be expressed as

$$\sum_j (Q^{cj}_{11} + Q^{ij}_{11}) \leq B_e.$$

4.19.4.6. Transportation Bullock carts are the predominant form of transportation in the study area, and most of the marketable surplus of crops is transported to market using bullock carts. Hence the transport constraint is expressed as

$$\Sigma\Sigma k(\mathrm{Tkm})_t = (\text{total})\ \text{production} - \text{self-consumption in rural areas} \times \text{distance}$$

$$\leq \text{demand for transport} \in \mathrm{Tkm}$$

$$\geq\left(\sum_{cj} Y_{cj} L_{cj} - \sum_{j} n_j^{\text{rural}}\right) a_d$$

$=$marketable surplus$\times$average distance.

4.19.4.7. Animal power In the study area, the total animal power used is the sum of animal power employed for land preparation and for transportation and must be less than or equal to the monthly availability. Hence this constraint can be expressed as

$$\sum_{p} C_{mp} L_{mp} + a_m^1 (\text{Tkm})_t^m - \sum_{b} a_b A_b \leq 0.$$

4.19.4.8. Human labor Application of human labor in the study area is mainly related to ploughing (with type p), mode of irrigation (i), maintaining cattle (type b), type of energy production (k), and transportation. The net amount of human labor actually employed must be less than or equal to the total available labor. Hence the constraint can be expressed as

$$-(H_m+O_m+M_m)+\sum_{\substack{mp\\p}}^{h} L_{mp}+\sum_{\substack{mi\\i}}^{h} L_{mi}+\sum_{\substack{mb\\b}}^{h} A_{mb}+\sum_{\substack{mk\\k}}^{h} O_k+\sum_{\substack{mt\\t}}^{h} (\text{Tkm})_t \leq O.$$

4.19.4.9. Operational holdings The area covered by the operational holding in the study area must be equal to the planted area, which in turn, is the sum of irrigated and rain-fed planted areas. Hence this constraint is expressed as

$$\sum_{m}\sum_{p} L_{mp} = \sum_{c}\sum_{m} L_{jcm}(Ci) = \sum_{m} L_{mi}.$$

4.19.4.10. Irrigation The study area mainly depends on canals, ponds, and river irrigation. Diesel/electric pumps have not been used to any appreciable extent. Thus, apart from human labor, other sources of energy find little use for irrigation in the study area. Hence the method of irrigation was not considered as a constraint in this study.

4.20. Application of the model

The linear programming model presented in this paper allocates the resources to the various subsystems of the system with the objective to maximize the total income from the rural as per the availability and requirements of the resources expressed

Table 22
Model results for the sample farms in the base year (1989)[a]

SI. No. (1)	Indicators (2)	Units (3)	Value (4)
1.	Objective value (Rs)	(Lakhs)	24.51
2.	Crop production	000'ton	
2.1.	Paddy	000'ton	0.91
2.2.	Coconut	000'ton	0.05
2.3.	Tapioca	000'ton	0.32
2.4.	Tamarind	000'ton	0.02
3.	Crop residue	000'ton	
3.1.	Availability	000'ton	1.86
3.2.	Utilization	000'ton	1.86
3.3.	Availability/capita	kg	1496
3.4.	Utilization	%	
3.4.1.	Fuel	%	13.72
3.4.2.	Feed	%	61.83
3.4.3.	Nutrients	%	24.45
4.	Dung	000'ton	
4.1.	Availability	000'ton	0.32
4.2.	Utilization	000'ton	0.32
4.3.	Availability/capita	kg	261
4.4.	Used as	%	
4.4.1.	Fuel (biogas)	%	3.05
4.4.2.	Nutrients	%	96.95
5.	Wood balance	000'ton	
5.1.	Availability	000'ton	0.025
5.2.	Utilization	000'ton	0.025
5.3.	Availability/capita	kg	19.91
5.4.	Available from	%	
5.4.1.	Plantation	%	2.83
5.4.2.	Forest	%	12.51
5.4.3.	Homestead	%	84.66
6.	Fuel (cooking)		
6.1.	Consumption[b]	GJ	556
6.2.	Consumption/capita	MJ	447.83
6.3.	Available from	%	
6.3.1.	Residue	%	80.66
6.3.2.	Wood	%	7.81
6.3.3.	Kerosene	%	0.00
6.3.4.	Others	%	11.53
7.	Digestible Crude Protein (DCP)		
7.1.	Consumption	000'ton	0.02
7.2.	Available/animal	kg	59.00
7.3.	Available from	%	
7.3.1.	Residue	%	99.00
7.3.2.	Grazing	%	1.00
7.3.3.	Bought	%	0.00
8.	Total Digestible Nutrient (TDN)		
8.1.	Consumption	000'ton	0.57
8.2.	Availability/animal	kg	1458

(continued on next page)

Table 22 (*continued*)

SI. No. (1)	Indicators (2)	Units (3)	Value (4)
8.3.	Available from	%	
8.3.1.	Residue	%	99.15
8.3.2.	Grazing	%	0.85
8.3.3.	Bought	%	0.00
9.	Fertilizers		
9.1.	Nitrogenous		
9.1.1.	Total consumption	000'ton	29.19
9.1.2.	Application	kg/ha	83.87
9.1.2.1.	Organic	kg/ha	9.28
9.1.2.2.	Inorganic	kg/ha	74.59
9.1.3.	Available from	%	
9.1.3.1.	Residue	%	1.26
9.1.3.2.	Dung	%	9.69
9.1.3.3.	Bought	%	88.94
9.1.3.4.	Biogas slurry	%	0.11
9.2.	Phosphatic		
9.2.1.	Total consumption	Ton	15.35
9.2.2.	Application	kg/ha	44.12
9.2.2.1.	Organic	kg/ha	5.73
9.2.2.2.	Inorganic	kg/ha	38.39
9.2.3.	Available from	%	
9.2.3.1.	Residue	%	0.51
9.2.3.2.	Dung	%	12.29
9.2.3.3.	Bought	%	87.02
9.2.3.4.	Biogas slurry	%	0.18
9.3.	Potassic	%	
9.3.1.	Total consumption	Ton	19.26
9.3.2.	Application	kg/ha	55.37
9.3.2.1.	Organic	kg/ha	10.86
9.3.2.2.	Inorganic	kg/ha	44.51
9.3.3.	Available from	%	
9.3.3.1.	Residue	%	1.56
9.3.3.2.	Dung	%	17.95
9.3.3.3.	Bought	%	80.39
9.3.3.4.	Biogas slurry	%	0.10

[a] Denotes the same value and the percentage within 5% difference.

[b] Denotes useful energy consumption.

by a set of equality and inequality constraints. GAMS-MINOS software was employed to maximize the revenue output subject to various energy-related constraints in the rural system. For illustrating the application of the model at the micro level, system inputs and technical coefficients for the rural segment of Kanyakumari district were estimated on the basis of the results of a survey data conducted by the Author.

Of the total quantity of 1 763 000 tons of crop residues, the model allocated 13.72, 61.83 and 24.45% crop residue to fuel, feed and nutrients, respectively. Of the total

Table 23
Validation of the model

SI. No.	Particulars	Survey data values	Generated values
1.	Residue (000'tons)	1.860	1.860
2.	Fuelwood (000'tons)	0.025	0.025
3.	Sources of fuelwood		
3.1.	Homestead (000'tons)	20.930	20.930
3.2.	Forest (000'tons)	3.090	3.090
3.4.	Plantation (000'tons)	0.700	0.700
4.	Dry dung (000'tons)	0.320	0.320
5.	Cooking energy		
5.1	Total consumption (%)	100.00	100.00
5.1.1.	Crop residue (%)	91.07	80.66
5.1.2.	Wood (%)	8.93	7.81
5.1.3.	Others (%)	–	11.83
6.	Soil nutrient		
6.1.	Crop residues:		
6.1.1.	Nitrogenous (%)	1.10	1.26
6.1.2.	Phosphatic (%)	0.12	0.51
6.1.3.	Potassic (%)	0.59	1.56
6.2.	Dung:		
6.2.1.	Nitrogenous (%)	15.44	0.69
6.2.2.	Phosphatic (%)	4.56	12.29
6.2.3.	Potassic (%)	11.52	17.95
7.	Feed:		
7.1.	Total digestible crude protein (DCP)		
7.1.1.	Crop residues (%)	53.36	99.00
7.1.2.	Grazing (%)	1.00	1.00
7.1.3.	Bought (%)	45.64	–
7.2.	Total digestible nutrient (TDN)		
7.2.1.	Crop residues (%)	99.00	99.15
7.2.2.	Grazing (%)	1.00	0.85

quantity of 123 000 tons of dung, the allocation to biogas and plant nutrients is 3.05 and 96.95%, respectively. The cooking energy needs of the households have been met from crop residues (80.66%), and fuelwood (7.81%), while other sources accounted for the balance of 11.52%. The total consumption of DCP and TDN for cattle feed are met from crop residues alone. Application of inorganic fertilizer is much higher than the organic part, with the inorganic part contributing a share of more than 80.00% of the total fertilizer application.

5. Conclusion

This paper presents two models for Micro Level Planning of a Rural Energy System along with a detailed comparison of data for primary and secondary sources. A model estimating the output of the rural system has been presented. The output of

Table 24
Model results for the Kanyakumari district in the base year (1989)

SI. No. (1)	Indicators (2)	Units (3)	Value (4)
1.	Objective value (Rs)	(Crores)	232.00
2.	Crop production	000'ton	
2.1.	Paddy	000'ton	129.96
2.2	Coconut	000'ton	36.97
2.3.	Tapioca	000'ton	194.43
2.4.	Tamarind	000'ton	6.74
3.	Crop residue	000'ton	
3.1.	Availability	000'ton	1763.00
3.2.	Utilization	000'ton	1763.00
3.3.	Availability/capita	kg	1496
3.4.	Utilization	%	
3.4.1.	Fuel	%	13.72
3.4.2.	Feed	%	61.83
3.4.3.	Nutrients	%	24.45
4.	Dung	000'ton	
4.1.	Availability	000'ton	123.00
4.2.	Utilization	000'ton	123.00
4.3.	Availability/capita	kg	105.00
4.4.	Usewd as	%	
4.4.1.	Fuel (biogas)	%	3.05
4.4.2.	Nutrients	%	96.95
5.	Wood	000'ton	
5.1.	Availability	000'ton	24.00
5.2.	Utilization	000'ton	24.00
5.3.	Availability/capita	kg	19.91
5.4.	Available from	%	
5.4.1.	Plantation	%	2.83
5.4.2.	Forest	%	12.51
5.4.3.	Homestead	%	84.66
6.	Fuel (cooking)		
6.1.	Consumption +	GJ	527088
6.2.	Consumption/capita	MJ	448.00
6.3.	Available from	%	
6.3.1.	Residue	%	80.66
6.3.2.	Wood	%	7.81
6.3.3.	Kerosene	%	0.00
6.3.4.	Others	%	11.53
7.	Digestible Crude Protein (DCP)		
7.1.	Consumption	000'ton	10.88
7.2.	Available/animal	kg	62.48
7.3.	Available from	%	
7.3.1.	Residue	%	99.00
7.3.2.	Grazing	%	1.00
7.3.3.	Bought	%	0.00
8.	Total Digestible Nutrient (TDN)		
8.1.	Consumption	000'ton	204.39
8.2.	Availability/animal	kg	1174

(continued on next page)

Table 24 (*continued*)

SI. No. (1)	Indicators (2)	Units (3)	Value (4)
8.3.	Available from	%	
8.3.1.	Residue	%	99.15
8.3.2.	Grazing	%	0.85
8.3.3.	Bought	%	0.00
9.	Fertilizers		
9.1.	Nitrogenous		
9.1.1.	Total consumption	Ton	8237.00
9.1.2.	Application	kg/ha	83.87
9.1.2.1.	Organic	kg/ha	9.28
9.1.2.2.	Inorganic	kg/ha	74.59
9.1.3.	Available from	%	
9.1.3.1.	Residue	%	1.26
9.1.3.2.	Dung	%	9.69
9.1.3.3.	Bought	%	88.94
9.1.3.4.	Biogas slurry	%	0.11
9.2.	Phosphatic		
9.2.1.	Total consumption	Ton	4333.00
9.2.2.	Application	kg/ha	44.12
9.2.2.1.	Organic	kg/ha	5.73
9.2.2.2.	Inorganic	kg/ha	38.39
9.2.3.	Available from	%	
9.2.3.1.	Residue	%	0.51
9.2.3.2.	Dung	%	12.29
9.2.3.3.	Bought	%	87.02
9.2.3.4.	Biogas slurry	%	0.18
9.3.	Potassic		
9.3.1.	Total consumption	Ton	5438.00
9.3.2.	Application	kg/ha	55.37
9.3.2.1.	Organic	kg/ha	10.86
9.3.2.2.	Inorganic	kg/ha	44.51
9.3.3.	Available from	%	
9.3.3.1.	Residue	%	1.56
9.3.3.2.	Dung	%	17.95
9.3.3.3.	Bought	%	80.39
9.3.3.4.	Biogas slurry	%	0.10

the system is computed from a set of well-defined inputs and a set of technical coefficients. The technical coefficients have been carefully evaluated based on data collected through a survey conducted by the Author in the study area, and from the data available from the literature. The influence of various factors on the output of the rural system is modeled through their effect on the corresponding technical coefficients. In the opinion of the author, the technical coefficients developed and presented in this paper can serve as useful indicators for other areas having similar socio-economic conditions and belong to similar agro climatic zones. The modification of this model into a linear programming model for optimum allocation of

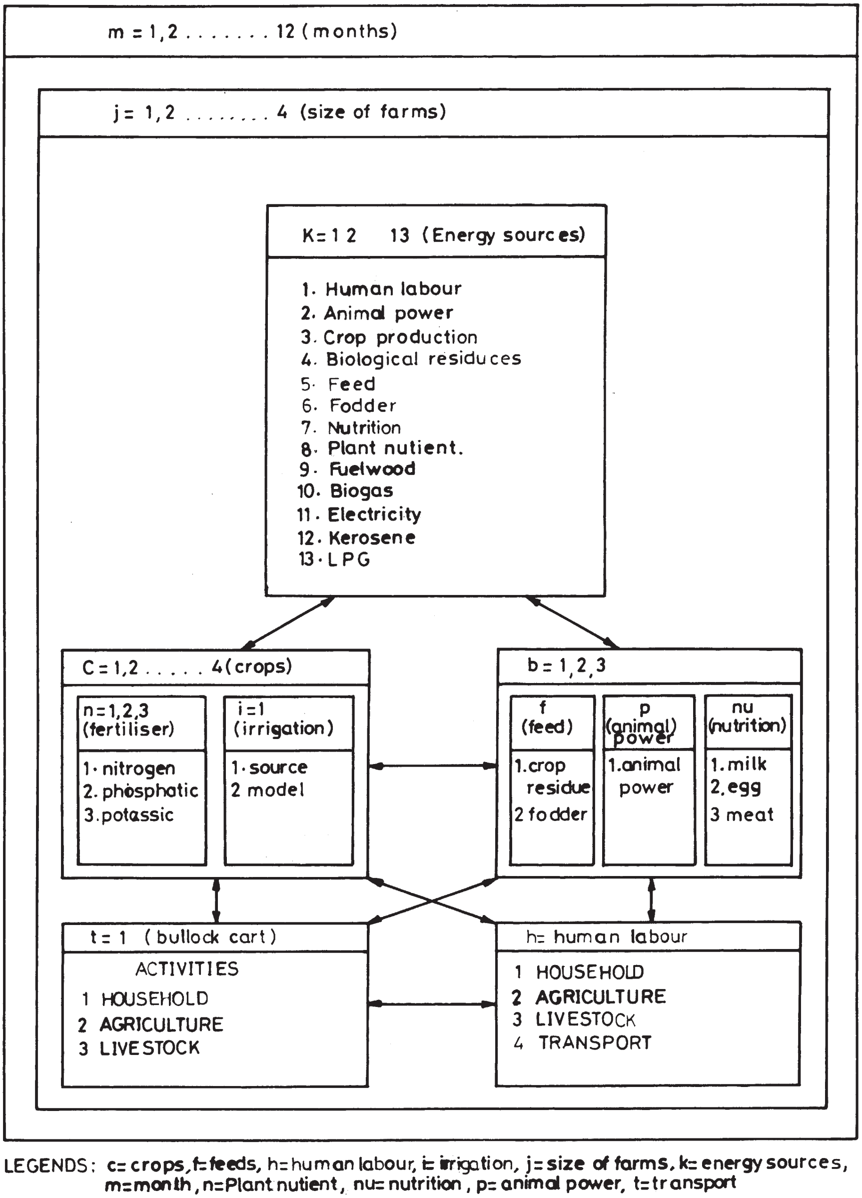

Fig. 23. Rural system energy model.

resources in the rural system is also presented. These models aim at maximizing the revenue output for the rural system through appropriate resource allocation subject to a number of energy as well as non-energy related constraints. The model quantifies the yield of major crops as well as their byproducts along with dung, and fuelwood

produced in the system. The model also allocates the energy resources to different sectors of the rural economic system.

The paper presents an overview of data for the socio-economic system of the target area which are available from literature as well as from District, Block, and Village level records. The lacunae in such data are discussed and a comparison with primary data obtained in a survey conduced by the Author is also presented.

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Appendix A. Nomenclature

Codes to the symbols of the linear programming model are as follows: activities are shown by upper-case letters. The running index is indicated by subscripts, the identification index is indicated by a superscript, and coefficients are shown in lower-case. However, only the first constraint is illustrated with symbol m and afterward, m is dropped for convenience (except in the case of ploughing and irrigation).

Max Z=maximization of revenue

where

1	crop residue, tons
2	dung, tons
3	fuelwood gathered from homesteads (labor costs only), tons
4	fuelwood from forest, tons
5	fuelwood gathered from wood plantations (requires labor, investment, fertilizer, irrigation), tons
6	biogas, 10^3 m^3
7	natural gas, 10^3 m^3
8	kerosene, 10^3 liters
9	electricity, 10^3 kWh
A_b	1000 head of type b animals
a_b	1000 animal days per 1000 animals of type b per month
A_{bj}	1000 type b animals owned by farms of size j
ad	assumed average distance of transport, km
a_m^1	animals days required for 100 Tkm
a^{w}	1000 animals days per 1000 ha of irrigated land

B^{f} store-bought feed, 10^3 tons
$B_{\mathrm{f},j}$ store-bought feed by farms of size j, tons
b_j^{h} household budget for fuel and electricity in jth class in 1000 monetary units
B_{kj} purchased energy in physical units by class j
B^{n} purchased chemical fertilizers
B_{nj} store-bought nutrients by farms of size j, tons
c crop index
C_b^{d} fraction of d_b that is collected or gathered
$(Ci)_j$ cropping intensity by j
C_{mb} 1000 animal days for land preparation of 1000 ha with animals (p=1)
d_b dung in dry matter per year per 1000 animals of type b, 10^3 tons
e_b^{d} dung required for l000 m^3 of biogas, tons
e_k primary energy contained in energy source k, 10^{12} J/$u(K)$
F_{cj}^{n} fertilizers applied on crop c by farm size j, tons
F_{cmj}^{r} crop residue used as feed in month m by class j, 10^3 tons of dry matter
$F_b^{(\mathrm{nut})}$ total digestible nutrient requirements per year for one animal, tons
$f_b^{(\mathrm{pro})}$ digestible crude protein requirement per animal per year, tons
f_{cb}^{r} feed required from crop residue per year by 1000 type b animals, 10^3 tons of dry matter
H_j total human labor days required by farms of size j
H_m monthly labor availability
h_m labor days for irrigating 1 ha m
h_{mb} labor days for maintaining 1 type b animal
h_{mi} labor days for irrigating 1 ha m by method i
h_{mk} labor days for producing or converting 1 μ(K) of type k energy
h_{mp} labor days for ploughing 1 ha by method p
h_{mt} labor days for 1 Tkm by method t
$H_{0,j}$ own labour days put in by farms of size j
j income class index
k index for energy resources
L_{cj} land area planted with crop c by farms of size j, ha
L_{cmj} land in month m for crop c by farms of size j, 10^3 ha
L^{jcm} land owned by farms of size j
L_m lead ploughed by method p, 10^3 ha
L_m land to be irrigated, 10^3 ha
L_{mi} land irrigated (and rain fed)
L_{mp} land ploughed by P, m
M_m migration labor, days
mu monetary unit
n index for type of nutrients
N_j^{d} dung used directly in manure, tons of dry matter
N_{cmj}^{r} crop residue used directly as nutrients in the field for crop c in month m by farm of size j, 10^3 tons of dry matter
$(\mathrm{nut})^{\mathrm{b}n}$ nutrients of type n from 1000 m^3 of biogas, tons

$(\text{nut})^{\mathrm{d}n}$	nutrients of type n per 1000 tons of dung, tons
$(\text{nut})^{\mathrm{r}}$	nutrients per ton of crop residue, tons
$(\text{nut})^{\mathrm{r}n}$	nutrients of type n of dry matter per 1000 tons of crop residue, tons
n_j^{rural}	rural self-consumption for j
O_c^{r}	crop residue used for other purposes, 10^3 tons of dry matter
O_m	monthly overwork
P_c	price of crop c per ton
P_f	price per ton of store-bought feed
P_k	price of purchased energy (kerosene and electricity) per physical unit, kL or 10^3 kWh
P_k^1	price of energy of type k per physical unit, $mu/u(k)$
P_n	price of ton of fertilizer of type n
$(\text{prot})^{\mathrm{r}}$	protein in 1 ton of crop residue, tons
Q_j^{ab}	biogis produced from dung, 10^3 m/yr
Q_j^{d}	dung used in households by farms of size j for cooking, tons
Q_k	energy production and purchase activities separate from utilization of it; k, energy sources
Q_{kj}^{ck}	energy source k used in cooking by farms of size j, $u(k)$
Q_{cmj}^{r}	crop residue for crop c used for burning by month m by farms of size j, 10^3 tons
Q_{kj}^1	activities of lighting with energy source $k1$ by farm of size j
r	crop residue
r_c	crop residue from crop c, tons of dry matter/ha
$(\text{Tkm})_t$	distance traveled by each mode t, 100 ton-kilometer (Tkm)
u	useful energy, $10/u/(k)$ rupees of y
$u(k)$	production activates in physical units
u_j^{ck}	cooking energy requirements by farms of size j, u 10^9 J/yr
u_j^{light}	demand for lighting for farms of size j
u_k^{h}	useful energy for energy source k in household cooking, 10^{12} J/$u(k)$
u_k^1	effective number of households that could be satisfied with 1000 units of k
w	wage rate per day
Y_{cj}	yield of crop c by farm of size j, tons/ha
Y_{cmj}	yield of crop c in month m by farm of size j, tons/ha

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